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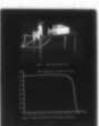
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ELIMINATION OF THE EFFECT OF SURFACE MICROTOPOGRAPHY IN AN IMPROVED SOIL SKIN MOISTURE DETERMINATOR

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JUNE 1979

Prepared by
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Under Contract DAEA18-76-C-0051
Contract Monitor: **L. EDWIN WILLIAMSON**

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report discusses the development of an instrument, the soil surface moisture determinator (SSMD), that provides soil surface moisture independent of the microstructure of the surface. Such an instrument was needed because the reflection characteristics of soils and sands depend on the moisture and microstructure of the surface layer; and under natural conditions; the many surfaces of different slope and exposure that account for the soil surface layer interfere with the simple relation		

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20. ABSTRACT (Cont)

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Tests performed with the SSMD show that the instrument can provide knowledge of the moisture content of the soils with one simple measurement. The results of the measurements do not provide information on the moisture condition within the soil, but the knowledge of the moisture of the surface layer can readily be correlated with all remotely detected data.

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Dr. C. R. Sreedharan did most of the test measurements. He and Dilip Roy Choudhury were instrumental in finishing the design, including all the electronics. The light flux instrument was built by the staff of the Electro-dynamics Lab at Utah State University under the supervision of Dean Shaffer and with substantial contributions by Nnawuihe "Mike" Okara.

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INTRODUCTION

The reflection characteristics of soils and sands depend considerably on the moisture and on the microstructure of the surface layer. Moisture generally darkens the appearance of a soil (reduces its albedo) by filling the airspaces between the soil or sand crystals with water and thus reducing the reflection surfaces. Over flat or graded soil surfaces, the moisture of the surface layer can be easily correlated with measurements of albedo or bidirectional reflections.

Under natural conditions, however, the many surfaces of different slope and exposure that account for the soil surface layer interfere with the simple relation between soil moisture and reflection.

Albedo measurements, the determination of the reflection of solar irradiance, measured with the wide angle ($2\frac{1}{\pi}$) pyranometers, are dependent on the solar angle. Most of the natural surfaces exhibit high albedo during the morning and evening (low sun angles) and lower during daytime. This was reconfirmed in many measurements (see, e.g., Kondratyev, 1969; Dirmhirn, 1964). Eaton and Dirmhirn (1979) investigated detailed reflection characteristics at natural sunshine conditions, using a high resolution MRIR Nimbus radiometer of 2 degrees aperture. Reflection indicatrices for several sun angles over sands and soils explained and confirmed the higher albedo during times of low sun angle. However, specific instrument characteristics contribute to this effect (Dirmhirn and Eaton, 1975). Albedo measurements alone were thus outruled as a means to determine soil moisture on the surface layer.

Any measurement close to the surface, like the bidirectional reflection method, is under natural conditions equally affected by moisture as well as by microstructure. In the case of sands, where the water holding capacity is low and associated variations of reflectivity due to moisture changes of the surface layer are small, the optical changes due to moisture may be overpowered by the changes due to the microstructure. A method that provides information of the moisture history of sands or soils has, hence, to be made independent of soil surface structure.

The method chosen and described here for the Soil Surface Moisture Determinator used the principle of viewing the same or a very close adjacent area through two filters, one in a water absorption band and the other spectrally close to, but outside, the water absorption. These two filters scan the same area on the surface, and the microstructure of the soil affects the measurements in both wavebands equally. Moisture changes, however, have a larger impact on the spectral range of the water absorption band. If made completely automatic, by rotating the filters and alternately exposing the same area through the two filters, an instrument can be developed that provides soil

surface moisture directly in one simple reading and independent of the microstructure of the surface. This instrument is easy to operate and is universal; i.e., it can determine moisture conditions over soil surfaces of any microstructure or slope and exposure.

THE INSTRUMENT

The objectives of the design of the Soil Surface Moisture Determinator (SSMD) are:

1. To design an instrument that permits detection of the moisture of the surface layer of sand and soil.
2. To measure soil surface moisture with this instrument, independent of the surface roughness and microstructure of the soil.

The constraint of the second objective complicates the design considerably. However, if the instrument should be used not over prepared surfaces but over natural soil or sand of different structure and surface ripple, the more sophisticated design is becoming necessary.

The entire equipment is housed in two portable boxes (figure 1). One box contains the light source, chopper, cooler, power supply, and the sensor assembly (figure 2); and the other box contains the digital voltmeter and the lamp power supply (figure 3). The units are interconnected by two cables.

PHILOSOPHY THAT LEAD TO THE DESIGN OF THE SSMD

The instrument consists of a light source, a two-filter spectral selection system, and a detector. Signal conditioning is achieved with built-in electronics.

The Light Source. To become independent of the natural illumination by the sun, a light source is used that operates with alternating (chopped) light. Any change of the flux of the sunlight can thus be eliminated. Besides being independent of the change of the sunlight, the instrument can be operated on a 24-hour basis.

A quartz iodine lamp is used for a light source. Its spectral characteristics are shown in figure 4. The lamp is housed in a small chamber providing space also for the chopper. The illumination of the sand is straight down in a cone of 20° angle.

The light flux can be adjusted but can vary somewhat without affecting the result. Only if the spectral composition of the emitted light changes detectably, deviations from the expected values might result. Since these deviations will be greater if the spectral passbands are far apart, the filters were selected in close proximity on the wavelength scale, 1210 and 1500 nm.

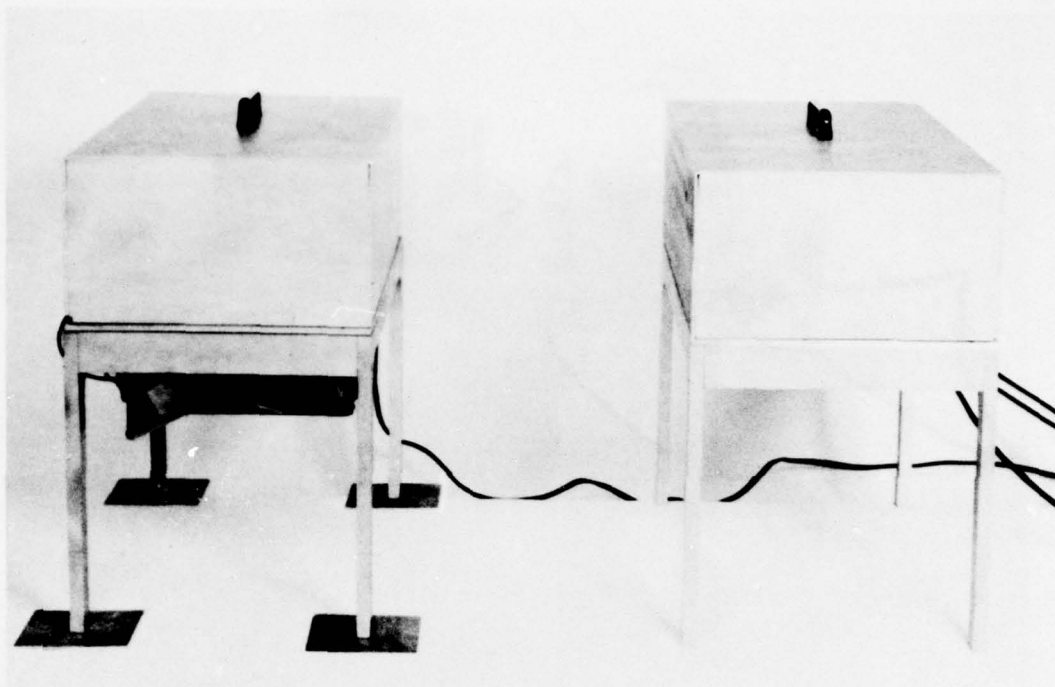


Figure 1. The two units composing the Soil Surface Moisture Determinator (SSMD).

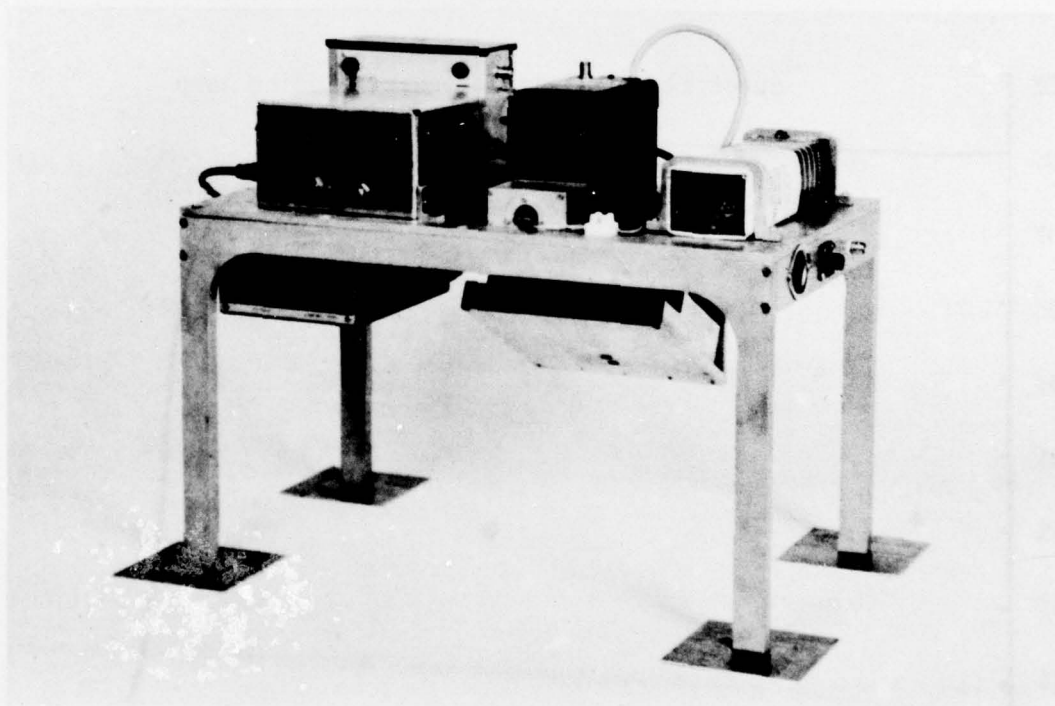


Figure 2. The lamp/chopper/sensor unit. Light source invisible (mounted in front of the sensor attachment (slanted)).

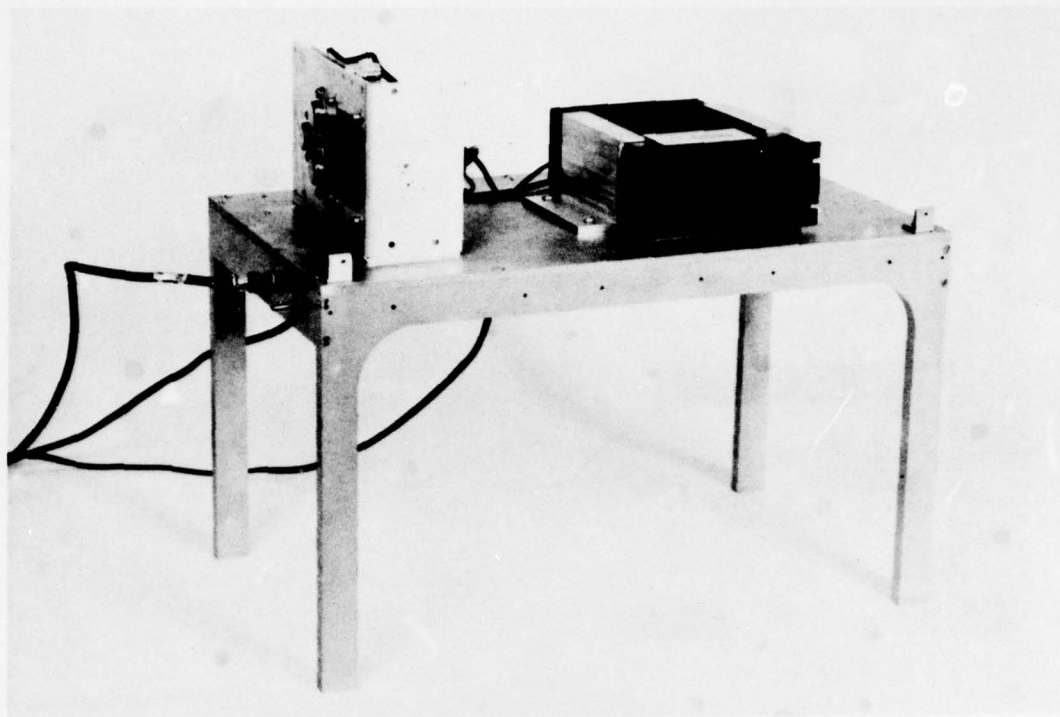


Figure 3. Power supply/readout unit.

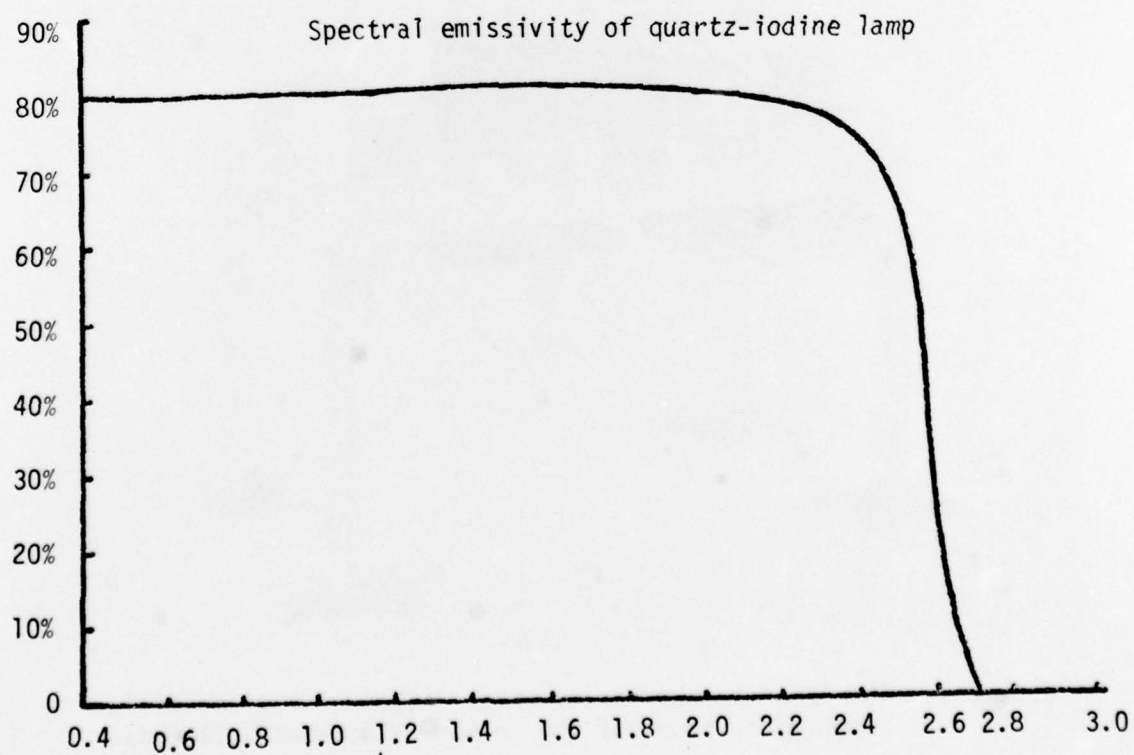


Figure 4. Spectral characteristic of the quartz-iodine lamp.

The Filter System. Oven dry, totally dehydrated, sands or soils show relatively uniform spectral reflectivity characteristics; generally a smooth line, increasing from the ultraviolet through the visible spectrum to the infrared (figure 5, Dirmhirn, 1964).

Moisture reduces the reflectivity in two ways: (1) because the previously air filled spaces between the sand crystals are now filled with water, the overall reflectivity throughout the solar spectrum (from 0.3 to 3 microns) decreases; (2) this decrease in reflectivity is stronger in the water absorption bands (Curcin and Petty, 1951) (figure 6) than in the wavelengths of weak water absorption. Air dry sand still has enough water left within some of the airspaces between the individual sand crystals that the water absorption bands can be clearly seen in the spectral reflectivity curve (figure 7, Eaton, 1976).

Researchers have found that the depth of the reflectivity bands can be correlated fairly close with the amount of moisture in the closest sand layer to the surface (Final Report, Contract DAEA 18-76-R-0037, 1976). Based on these findings, a filter system can be chosen to represent the moisture of the soil surface layer. Various filter combinations were tried for best results (table 1). The combination finally chosen for the presented instrumentation is 1500 nm/1210 nm. These filters have a diameter of 1 inch and are mounted side by side in the filter and sensor-attachment. A slow-speed chopper alternates the exposure of the sensor to the two filters. The sensor is set well behind the filters, so that it "sees" very close areas on the sand.

This design could be improved by rotating the filters in front of the sensor. Thus, exactly the same area would be exposed to the sensor through the alternating filters. This approach, however, created difficulties in the mechanical as well as electrical design that could not be overcome with the allotted funding and time. At the present design, the instrument could be used over surfaces that do not change strongly their microstructure within the illuminated area. The microstructure itself (microdunes due to drifting sand, slopes, or level terrain, etc.) does not affect the measurements of the moisture of the soil surface layer.

Scanning the sand surface with the two-filter method renders the surface moisture condition immediately and allows conclusions on the general reflectance of the area independent of other parameters. It is thus superior to any other method of areal reflectance determination.

For example: Measurements of the albedo with instruments of hemispherical detectors are strongly dependent on the geometry of the surface underneath as can be seen from the fisheye photograph of the dune area (figure 8). Albedo determinations over sloped terrain require slope parallel measurements that are hard to perform exactly (Tooming, 1960; Dirmhirn and Eaton, 1975). Changes in albedo due to

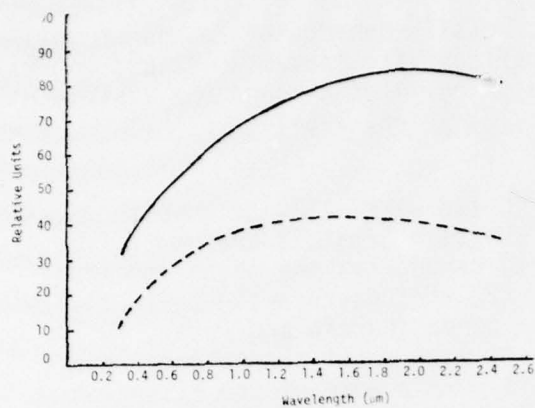


Figure 5. Spectral reflectance of totally dehydrated sands or soils (from Dirmhirn, 1967)

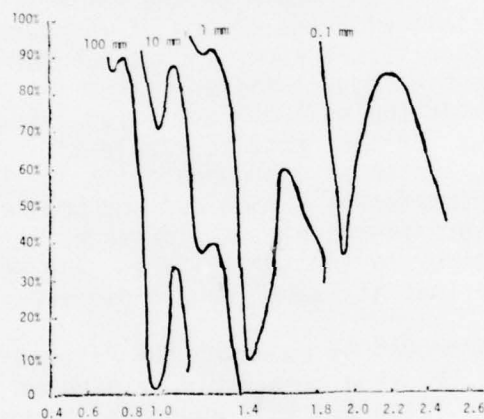


Figure 6. Water transmission within the solar spectrum (from Curcin and Petty, 1951).

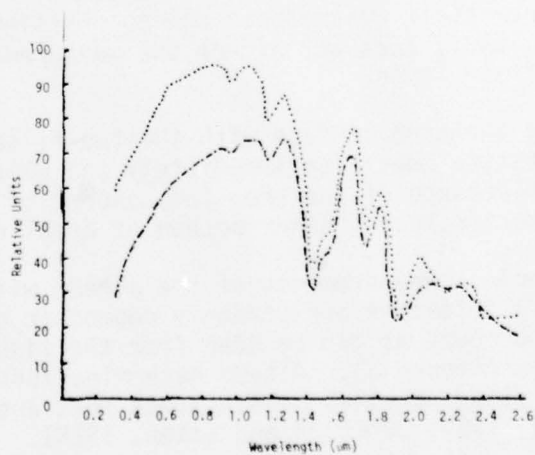


Figure 7. Spectral characteristics of white gypsum sand (from Eaton, 1976).

TABLE 1. TRANSMISSION CHARACTERISTICS OF VARIOUS INTERFERENCE FILTERS
TESTED FOR USE WITH SSMD

Center Wavelength λ_0 (nm)	Bandwidth at Half Peak Transmission	Peak Transmission
780	35	45
980	100	45
1210	34	73
1400	40	69
1500	100	40
1712	110	60
1996	110	60

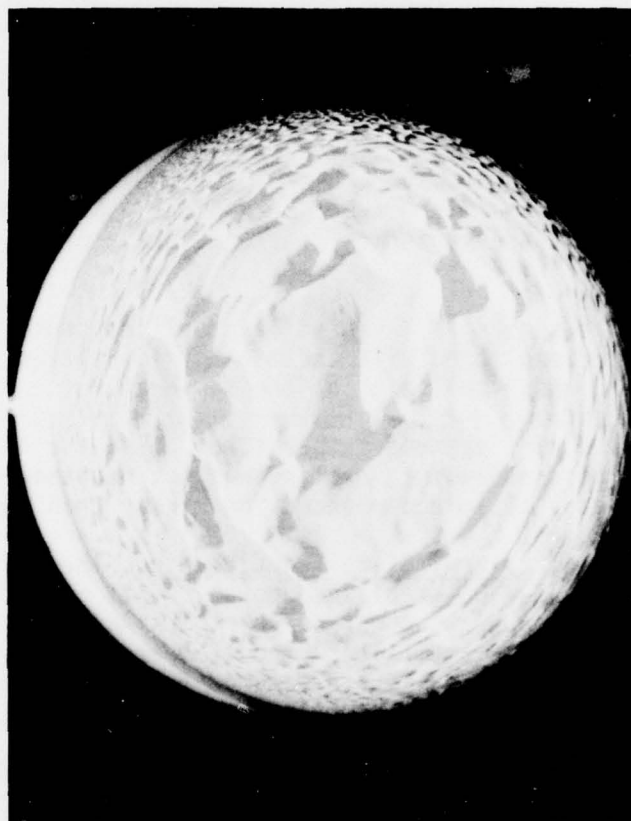


Figure 8. Fisheye photograph of the dune area.

slopes could easily be mistaken for moisture changes and vice versa. Variations over the whole scale from dry (air dry) to saturation over white gypsum sand is only about half the change that can be encountered due to slope angles and orientation. The differential filter method described here is totally independent of slope angle and orientation.

Other methods, like the use of a light source from an angle and the measurement of the directional reflectance (Middleton and Mungall, 1952; Hapke and Van Horn, 1963), fail to provide reasonable data during cases of supersaturation (Final Report, Contract DAEA 18-76-R-0037, 1976). Figure 9 shows a history case from one of those efforts. During supersaturation the bidirectional reflectance is extremely high due to specular reflection on the exposed spaces filled with water. As the water subsides, bidirectional reflectance decreases rapidly until it reaches a minimum. When the airspaces close beneath the surface are filled with water, the light waves can penetrate deeper into the soil. From this minimum, the bidirectional reflectance increases steadily as the soil dries. Records of this type, however, passing through a minimum and increasing to both sides, to higher and lower degrees of moisture in the surface layer, create an ambiguity that needs additional observations to resolve.

Similarly, measurements of polarization of reflected sunlight or artificial light sources are highly dependent on the general orientation of the majority of the sand crystals, and thus dependent on wind drift direction. The moisture history of the surface layer can thus be overpowered by the microstructure and the associated crystallographic reflection characteristics of the majority of the sand particles.

The Sensor. The sensor is a cooled lead sulfide photoconductive cell. Cooling is accomplished with thermoelectric Peltier device and circuitry. Cooling and stabilizing of the temperature, especially in hot climates, guarantee a low dark current and the proper functioning of the electronics during extreme temperatures. For the laboratory experiments with this instrument, cooling was not necessary at room temperatures; however, it is recommended for higher than 35°C.

The Electronic Circuitry, Signal Conditioning. The quartz iodine lamp is powered by a 15-V DC stabilized power supply operating on 115-V AC main. The light chopper also works from 115-V AC main at the chopping frequency of 670 Hz. The filter chopper operates at a low frequency of 8 Hz. The sensor cooler is powered from a highly regulated 1-V 1.5-amp DC power supply also working from 115-V AC.

The signal derived from the sensor is a 670-Hz sine wave carrier with an 8-Hz amplitude modulation due to the alternating exposure of the sensor through the two filters. The choppers also generate, through separate circuitry, two reference signals synchronized with the chopping.

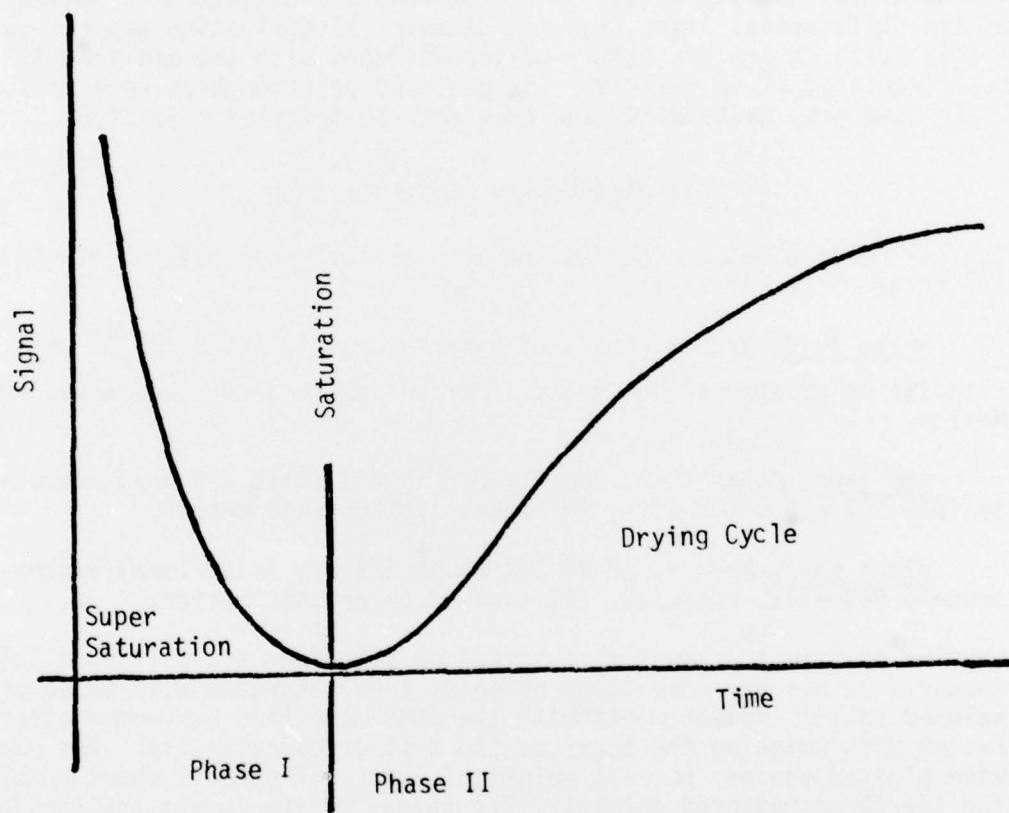


Figure 9. History case of soil moisture of the surface layer and bidirectional reflectance curve.

The signal is amplified and then synchronously detected at 670 Hz using the reference signal. This way the message contained in the envelope is extracted; and after further amplification, this signal at 8 Hz is again synchronously detected to give a DC output proportional to the amplitude. This output is displayed on a digital voltmeter. The amplitude of the 8 Hz signal depends on the relative intensities of the light transmitter through the two filters--which, in turn, depend on the amount of moisture on the soil surface. Therefore, the voltmeter reading will be dependent on the moisture content of the soil surface.

A certain nonlinearity exists in the correlation between soil moisture and the differential light signal. However, linearization was not part of this research and can easily be accomplished with the addition of more circuitry, if so desired. The measured relationships were conclusive and easy to identify and thus met the original objectives.

TEST MEASUREMENTS WITH THE SSMD

The correlation between output and soil surface moisture was determined for three different soils.

White sand, predominantly of gypsum crystals ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) with association of some sodium salts, from the White Sands Dune area, New Mexico.

Red sand, Aiken soil, Humult, 2.5 YR 3/6 moist 4/8 dry, approximately 30% clay, 40% silt, 30% sand, 1.5% organic matter.

Black soil, Xerall, 10 YR 3/2 moist 5/2 dry (silt loam) approximately 60% silt, 20% clay, 20% sand, 3.5% organic matter.

Samples of 3 mm thickness were spread on styrofoam trays (figure 10), measured at air dry condition, weighed, then saturated with water and weighed again. Measurements with the SSMD were then performed alternating with weighing the trays as the soil dried naturally. The data were plotted against percent weight of water. Figure 11 shows results for the three measured samples. The shapes of the curves are similar for all samples, though the water holding capacity varies considerably. For white gypsum sand, saturation occurs at 30 weight percent, while the fine-grained black soil reaches saturation at 65 weight percent. The optical color change and measured difference between dry and saturated soil is by far larger in the latter case than in the case of white gypsum sand. In figure 11, the ordinate data measured with the SSMD are presented in relative units.

An attempt to normalize these curves could be accomplished for the two sand type soils, while the fine-grained black soil deviated from the general curve (figure 12). The SSMD was used in this case in a different mode by measuring filter ratios. Figure 11 suggests that

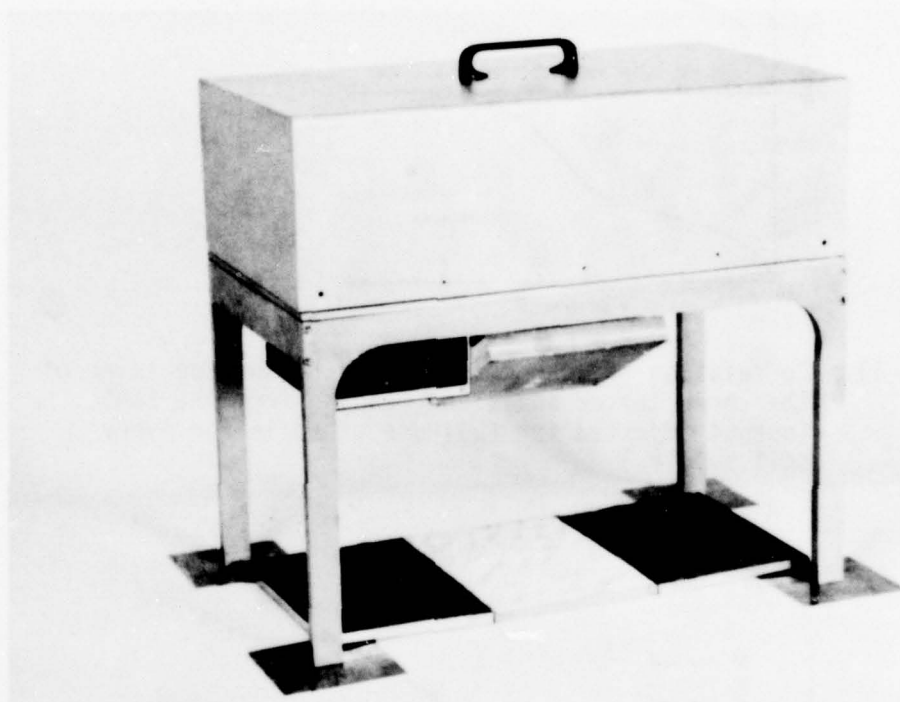


Figure 10. The SSMD with the three selected soil samples. Samples are shifted into the position of the white gypsum sand as measurements of the different soils are taken.

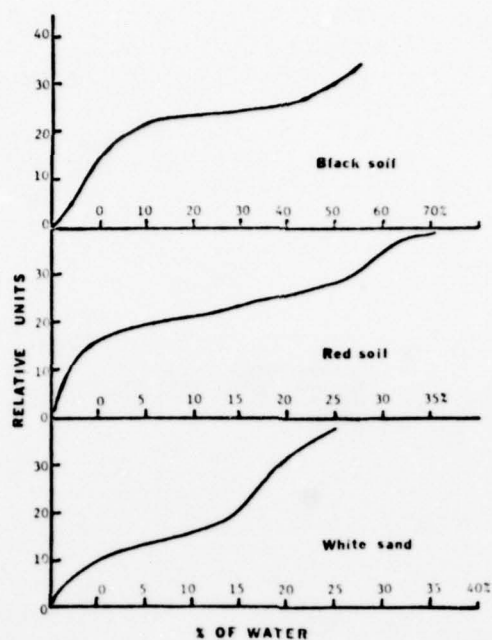


Figure 11. Correlation between moisture of the surface layer of the three tested soils and reading from the SSMD (output adjusted for full use of scale for every soil sample.)

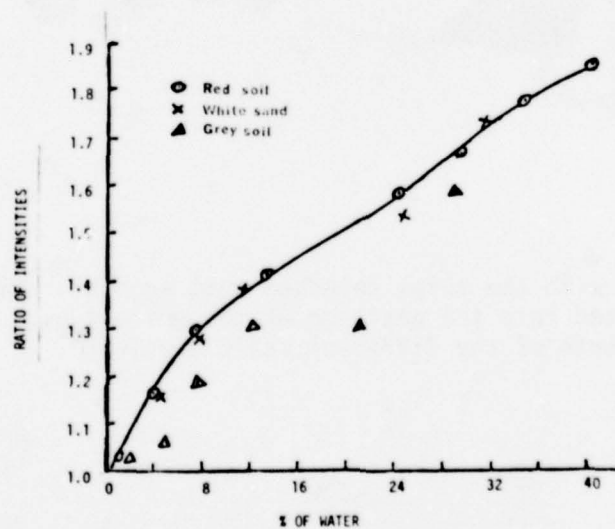


Figure 12. Normalized values and curves for the three tested soils, when operated in the ratio mode.

curves of slightly different shapes might have to be associated with the moisture history of soils of different grain size. Tests of more soil samples will be necessary to decide if this is the case.

During the testing, the microstructure of the soil was of no significance for the measured data. The distance of the sample from the light source and filter wheel can vary within predetermined limits, given by the geometry of the light cone and sensor/filter housing angle. Within these limits, only the general signal level is affected. To stay within the required distance/heights limits, the 4- by 4-inch level feet of the instrument box are provided. When the box is placed on a natural surface, deviations in heights due to surface roughness will not affect the reading.

CONCLUSIONS AND DISCUSSION

The SSMD can provide knowledge of the moisture content of soils by performing one simple measurement. The measured large-grained sands of strongly different color could be generalized when the instrument was operated in the ratio-mode. Testing of a wide variety of soil samples is necessary to decide if one generalized curve can be used for all soils, or a family of curves for soils of different grain size.

Though the results of the measurements with the SSMD do not provide information on the moisture condition within the soil, the knowledge of the moisture of the surface layer can readily be correlated with all remotely (from flying platforms like planes or satellites) detected data. In this context, the method is of far reaching importance.

It shall be mentioned that the here-developed method for microscale observations can be modified for use on airplanes or helicopters and can thus be adapted for mesoscale observations of the moisture condition of the ground surface.

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